

EUROPEAN PATENT APPLICATION

Application number: 86302565.6

Int. Cl.⁴: G01R 31/28, H05K T3/02,
H05K T3/00

Date of filing: 07.04.86

Priority: 24.04.85 US 726498

Date of publication of application:
17.12.86 Bulletin 86/46

Designated Contracting States:
AT BE CH DE FR GB IT LI LU NL SE

Applicant: PROMETRIX CORPORATION
3255 Scott Boulevard Building 2 Suite A
Santa Clara California 95054(US)

Inventor: Mallory, Chester
1073 Lucot Way
Campbell California 95008(US)
Inventor: Perloff, David Steven
1089 Valley Forge Drive
Sunnyvale California 94087(US)
Inventor: Hung, Van Pham
1753 Daltrey Way
San Jose California 95132(US)
Inventor: Droblisch, Sándor
15362 Elm Park
Monte Sereno California 95030(US)

Representative: Bayliss, Geoffrey Cyril et al
BOULT, WADE & TENNANT 27 Farnival Street
London EC4A 1PQ(GB)

Apparatus and methods for semiconductor wafer testing.

EP 0 201 205 A1
An automatic system for performing sheet resistivity testing on surface layers of semiconductor wafers, including a wafer handling stage having a platform (23) for carrying a semiconductor wafer, and an arrangement (100) for mounting the platform for rotation about a central axis and for translation of the platform orthogonal to a major surface thereof. A platform drive translates the platform between a wafer test position and a wafer load position, and a stage drive (102, 103) rotates the platform to accurately located angular test positions. A probe handling arrangement (150) includes a carriage for carrying a test probe (200) parallel to the major surface of a wafer on the platform and a carriage drive (153, 157) translates the carriage between a parked position in which a test probe thereon is positioned adjacent and clear of the platform and accurately located test positions along a radius of the platform. The carriage carries a resistivity test probe which

includes test probe element for contacting the surface of a semiconductor wafer. A light tight housing surrounds the platform and includes an access for (19) therein facing the platform and positioned intermediate the wafer load position and the wafer test position of the platform. The access door translates under controlled motor drive between a closed position and an open position which permits the platform to translate between the wafer load and wafer test positions. Sensor arrangements cooperate with a safety inhibit circuit to preclude destructive movement of components when position conflict is sensed. All movements and measurements are under microcomputer control.



EP 86 30 2565

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl. 4)
Y	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 17, no. 3, August 1974, page 880-881, New York, US; R.E. HOGAN et al.: "Precision mechanism for use in a system requiring precise alignment" * Pages 880,881 *	1	G 01 R 31/28 H 05 K 13/02 H 05 K 13/00
Y	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 21, no. 10, March 1979, pages 4086-4087, IBM Corp., New York, US; W. SCHWARZ: "Rotatable wafer chuck for testing" * Pages 4086-4087 *	1	
A	IBM TECHNICAL DISCLOSURE BULLETIN, vol. 17, no. 8, January 1975, pages 2220-2221, New York, US; M. GAGNE: "No-edge contact wafer orientor"		TECHNICAL FIELDS SEARCHED (Int. Cl. 4) G 01 R H 05 K
A	US-A-4 328 553 (R. THORBJOERN)		
The present search report has been drawn up for all claims			

Place of search
THE HAGUE

Date of completion of the search
07-08-1986

Examiner
KUSCHBERT D.E.

CATEGORY OF CITED DOCUMENTS

- X particularly relevant if taken alone
- Y particularly relevant if combined with another document of the same category
- A technological background
- O non-written disclosure
- P intermediate document

- T : theory or principle underlying the invention
- E : earlier patent document, but published on, or after the filing date
- D : document cited in the application
- L : document cited for other reasons
- & : member of the same patent family, corresponding document

APPARATUS AND METHODS FOR SEMICONDUCTOR WAFER TESTING

This invention relates generally to apparatus and methods for testing semiconductor wafers to ascertain physical and electronic characteristics thereof. This invention also relates to apparatus for automated handling and positioning of workpieces such as semiconductor wafers. In a specific embodiment, this invention relates to systems and methods for sheet resistance mapping of semiconductor wafers to test the performance of semiconductor wafer manufacturing equipment utilized to form surface layers of specific target conductivity value as part of the process of manufacturing semiconductor devices such as, for example, large scale integrated circuits.

The invention described in this specification may be applied generally in the testing of semiconductor wafers utilizing testing processes carried out in a contact or non-contact mode, i.e., utilizing test probes of the type which require contact with the surface of the semiconductor wafer or test probes which perform their testing function in a position adjacent to, but not in contact with, the surface of the wafer. To understand the importance of the invention to the semiconductor industry, it will be helpful to first consider some background information on the status of the industry and the particular importance of performing automated resistivity testing on semiconductor wafers which have been subjected to ion implantation.

Large scale integrated circuits involve the integration on a single semiconductor chip of a large number of individual semiconductor devices which are interconnected into a completed circuit. Very great improvements in the scale of integration of semiconductor devices on integrated circuit (IC) chips and the speed of operation of such devices have been achieved over the past several years. In other words, improvements have resulted in substantially increased numbers of individual semiconductor devices being formed in the same area of a semiconductor chip. These improvements have been made possible by a number of advances in integrated circuit manufacturing equipment as well as improvements in the materials and methods utilized in processing virgin semiconductor wafers into IC chips. The most dramatic advances in manufacturing equipment have been improved apparatus for lithography and etching which define the device and circuit patterns and improved systems for implanting of conductivity modifying impurities into the semiconductor wafer.

Generally, the density of integrated circuits and their speed of operation are dependent largely upon the accuracy and resolution of the lithography and etching apparatus used to form the patterns of circuit elements in masking layers on the semiconductor wafer. However, density and speed are also dependent upon tight control of the profile of doped regions in the wafer, that is, regions to which substantial concentrations of conductivity modifying impurities have been added. Tight control of wafer doping can best be achieved in today's technology using ion implantation techniques and equipment. When ion implantation equipment is operating properly, highly uniform doping of the semiconductor wafer can be achieved. This will result in high yield of properly working integrated circuits if other aspects of semiconductor processing are properly carried out. However, if the ion implantation equipment is malfunctioning so that improper or non-uniform dosages are present in the semiconductor wafer, the yield of properly working integrated circuit devices will fall off dramatically. Thus, it has become increasingly important in controlling the quality and yield of semiconductor processing to have effective in-process control monitoring of the proper operation of ion implantation systems.

Figs. 1A-1C illustrate the use of a sequence of ion implantation steps in fabricating conductor-insulator-silicon integrated circuit devices on a semiconductor wafer. Fig. 1A illustrates a first ion implantation step which may be performed on the P-type wafer 10 to produce a light implant in the field regions 14 of the wafer. Field regions 14 are defined at this point as the regions of the wafer which are not covered by the regions of photoresist 11. These regions of photoresist 11 are formed using a standard lithography process in which a thin layer of photoresist is spread over the entire surface of the wafer and then selectively exposed through a mask pattern or a directly scanned and modulated electron beam. This is followed by a developing step which removes areas of the photoresist which have been exposed to the light or to the electrons. A thin layer of thermal oxide 12 may be present over the exposed surfaces of the semiconductor so that the ion implantation in the field regions 14 will be made through the thin oxide layer.

sults of such testing techniques are discussed in detail in the following papers and publications, which are incorporated herein by reference:

D. S. Perloff et al., "Dose Accuracy and Doping Uniformity of Ion Implantation Equipment," Solid State Technology, February 1981, pp. 112-120;

Andrew B. Wittkower, "The Effect of Ion Implanter Design Upon Implant Uniformity," Solid State Technology, September 1982, pp. 77-81;

David S. Perloff, "Four-Point Probe Correction Factors for Use in Measuring Large Diameter Doped Semiconductor Wafers," Journal of the Electrochemical Society: Solid-State Science and Technology, November 1976, pp. 1745-1750; and

D. S. Perloff, et al., "Contour Maps Reveal Non-Uniformity in Semiconductor Processing," Solid State Technology, February 1977.

Fig. 4 illustrates a printout of a contour map which shows a pattern of non-uniform implantation of a wafer. The heavy contour line represents the mean resistivity value of the wafer. The lighter contour lines outline regions which differ from the mean value by a preset percentage. The + and - symbols represent test sites for which the resistivity value is above and below the mean value, respectively. Fig. 5 illustrates a printout of two diameter scans on the same wafer. Here the actual resistivity values are plotted as a function of position of the test site on the diameter of a wafer. From these tests and printouts, the engineer in charge of a process can determine whether the ion implantation equipment is operating properly. Specific discussion of the diagnostic capability of the resistivity tests is contained in the above-referenced articles.

Figs. 6 and 7 illustrate the two configuration resistivity probing techniques which are preferred for accuracy in making sheet resistance measurements on a semiconductor test wafer. The four points of the probe 90 are shown in contact with the surface layer 81 of a semiconductor test wafer 80. A four-point probe is a mechanical device consisting of four spring-loaded metallic probe tips 91A-91D which are brought into contact with the surface of the wafer.

Fig. 6 shows a standard probe configuration in which a constant electrical current is introduced into the wafer through the outer probe tips 91A and 91D, and the voltage drop is measured across two inner probe tips 91B and 91C. In Fig. 7, an alternate probe configuration is shown in which the constant current is introduced through probe tips

91A and 91C and the voltage drop is measured across probe tips 91B and 91D. Use of these two test measurements makes it possible to determine sheet resistance to a high degree of accuracy even at testing positions which are near the edges of the semiconductor wafer.

In a co-pending and commonly assigned patent application entitled "Apparatus and Methods for Resistivity Testing," Serial No. 704,296, filed February 22, 1985, a novel arrangement for orienting the resistivity test probe for improved accuracy in performing four-point probe sheet resistance measurements on conductive surface layers of a semiconductor wafer is disclosed. The specification of that application is hereby incorporated by specific reference.

The automated resistivity tester which has been essentially the industry standard for a number of years is the Kokusai Model VR30A resistivity tester. In this Kokusai system, the wafer platform is arranged to translate between a wafer load position directly in front of the main front wall of a light tight enclosure and a wafer home position in which the wafer platform is located entirely within the light tight enclosure and a stationary probe head mounted in a cantilevered fashion over the platform is positioned at the precise center of the wafer platform. The test probe remains stationary and the wafer platform is arranged to rotate to accurately located angular orientations so that both diameter scans and contour scans of a semiconductor wafer on the platform can be performed. Moving between a wafer load position and the home position of the wafer platform, the wafer platform moves through a swinging door arrangement in the main front wall of the enclosure.

While the Kokusai system functions in a generally satisfactory manner, there are a number of disadvantageous aspects of the wafer handling technology provided therein. First, it is difficult to interface the Kokusai unit to an automated wafer handling system for loading the wafers onto the wafer platform. The automated wafer loading system must either be placed directly in front of the test system enclosure or in some other position near the front of the unit where it tends to interfere with the operating controls of the system. Use of an r, θ wafer stage together with a stationary probe head requires that the overall apparatus for translating the wafer stage between a wafer load position and home position consume a large area of the overall test bench footprint of the system. The requirement that the wafer stage move out of the front enclosure wall limits the overall system enclosure volume which is available for packaging the

probe arm in a cantilevered manner at one end for translation orthogonal to the wafer platform between probe up and probe down positions. In this arrangement a probe drive arrangement is coupled to the probe arm to drive the probe arm between the probe down and probe up positions.

The preferred embodiment of this invention also features a sensor and function inhibit arrangement which precludes the operation of various aspects the drive arrangements under conditions when damage to one of the components of the system could result. For example, in the broadest context, the sensor arrangement includes a probe location sensor associated with the carriage for sensing when the test probe arrangement is in the parked position and a platform position sensor arrangement associated with the wafer handling stage for sensing when the platform is in the wafer test position. A control circuit is coupled to the platform and stage drive arrangements for controlling the operation thereof. Coupled between the control circuit and the platform and stage drive arrangements is an inhibit circuit which is also coupled to the probe location and platform position sensors for sensing the state of these sensors. The inhibit circuit inhibits operation of the platform drive means (i.e., the one that controls raising and lowering of the wafer stage) except when the probe location sensor signals that the carriage arrangement is in the parked position. The inhibit arrangement also inhibits operation of the carriage drive which causes the translation of the carriage except when the platform position sensor senses that the wafer platform is in the wafer test position (i.e., stage down).

In a system in which the test probe is intended for contacting a semiconductor wafer on the wafer platform, a probe status sensor arrangement is provided for sensing when the probe arm is in the probe up position. The inhibit arrangement further inhibits operation of either the platform or stage drive arrangement except when the probe status sensor senses the probe arm is in the probe up position.

In an embodiment of the invention which mounts the wafer stage in a light tight enclosure with an access door immediately above the wafer stage platform, a door drive arrangement is provided for moving the door between open and closed positions and a door sensor system is provided for sensing when the access door is in full open position so that it is safe to raise the platform to the stage up (wafer load/unload) position. In this embodiment, the inhibit circuit arrangement is also coupled to the door sensor arrangement so that the platform drive arrangement is inhibited except

when the probe location sensor senses that the carriage means is in the parked position and the door sensor senses that the door is in the full open position.

Another aspect of this invention features an arrangement for determining the position of a wafer on the wafer platform and the size of the wafer on the wafer platform. This aspect of the invention features a reflection sensor mounted on the carriage arrangement at a prearranged position proximate the prearranged location of the test probe for detecting when the sensor is positioned at the edge of a wafer on the platform as the test probe is scanned from the parked position toward the center of the wafer and vice versa. A control circuit is coupled to the sensor and to the platform stage and carriage drive arrangements for operating all of the drive arrangements in a prearranged sequence while monitoring the output of the sensor to determine the radial and angular coordinates (r, θ) of at least three separate edge points of the wafer and to determine from those coordinates the actual radial and angular coordinate of the center of the wafer and also the size of the wafer itself.

The workpiece staging system of this invention has the advantage of compactly carrying a workpiece between a load position in which the stage is up and a workpiece operate (stage down) position while also providing for rotation of the workpiece about a central axis of this stage. As applied to handling semiconductor wafers, this capability dramatically adds to the convenience of wafer handling for the operator since the wafer stage is presented to the user at a top surface of the system where it is very convenient for the user to manually load and unload the wafers. Furthermore, the wafer staging system is easily interfaced to existing automated wafer handling systems which can be mounted adjacent the housing which encloses the entire test system and still have convenient access from a number of angles to the wafer stage platform.

By providing for translation of the probe head relative to the wafer platform, instead of translating the wafer platform relative to the probe head, a much more compact arrangement of the wafer stage and the probe scanning mechanisms can be achieved. This permits the packaging of all of the electronics of an automated resistivity tester, for example, inside a single enclosure with all the attendant advantages and conveniences. Signal leads are shorter, leading to greater noise immunity and connection reliability.

Fig. 25 is a left hand end view of an r, z stage in accordance with this invention.

Fig. 26 is a detailed view showing a probe down sensor arrangement in accordance with this invention.

Fig. 27 is a partial perspective view of an automated semiconductor wafer testing system showing an optional protective traveling shroud.

Fig. 28 is a partial section view showing the structural arrangement of the optional traveling shroud.

Fig. 28A is a partial view of the shroud guide pin and channel arrangement taken along the lines A-A in Fig. 28.

Fig. 29 is a system block diagram for a computer controlled automated resistivity test system in accordance with this system.

Fig. 30 is a schematic diagram of the motor, position sensor, and air and vacuum system in accordance with this invention.

Fig. 31 is a schematic circuit diagram of a safety inhibit system in accordance with this invention.

Fig. 32 is a schematic illustrating the wafer position and size determining feature of this invention.

Fig. 33 illustrates the software control architecture of an automated resistivity test system in accordance with this invention.

Figs. 34-41 are software flow charts depicting computer controlled operation of an automated resistivity test system in accordance with this invention.

Since Figs. 1-7 have been described in the introductory portion of this specification, further description thereof is unnecessary at this point.

Fig. 8 depicts a perspective view of an automated resistivity test system which is the currently preferred embodiment of the wafer handling and probing features of this invention. The general concepts and features of this invention will be described in terms of the preferred embodiment of an automated resistivity test system. However, it should be understood that the features of this invention are readily adaptable to other types of

semiconductor wafer testing, including capacitance voltage measurements, film thickness measurements, and acoustic coupled lifetime measurements. The techniques of acoustic coupled lifetime measurements were described in a paper given at an ASEE Technical Session in January 1985 by R. Bharat et al. Various types of film thickness measurements can be utilized, including color comparison, variable angle monochromatic fringe observation, constant angle reflection interference spectroscopy, and ellipsometry. These various film thickness tests are described by William A. Pliskin and Stelvio J. Zanin in "Film Thickness and Composition," Chapter 11 of the Handbook of Thin Film Technology, edited by Maissel and Glang (McGraw-Hill 1970).

The automated resistivity test system 10 depicted in Fig. 8 places all of the mechanical and electrical hardware of the system in a single integrated enclosure which includes a base casting 11 to which is hinged at the front edge a front cover 12 which swings down to provide access to the front interior of the cabinet. A diagnostic panel (not shown) is preferably located inside the front cover. Top cover 13 and the side panels 14 are removable from the housing for access to the interior for servicing of the electrical and mechanical components contained therein. The cover, side and back panels are removably mounted on a steel frame (not shown).

As Fig. 8 shows, an optional pull-out keyboard 15 may be provided in the base plate 11. This manual keyboard may have the key functions depicted in Fig. 9. With these key functions, the resistivity test system can be configured as a self-contained automated resistivity tester with limited overall test protocol features.

A liquid crystal display 16 is provided on the front cover 12 for displaying test parameters, test results, and status information. A more limited control panel 17 is provided with just a few control functions. More extensive system control keys may be included on this control panel for the self-contained automated resistivity tester mentioned above.

Top cover 13 has a rectangular opening 18 formed therein and a sliding cover or door 19 is provided to complete a darkened light tight enclosure into which the wafer holding platform 23 drops after a wafer (not shown here but described below) is loaded thereon. The bottom panel 20 of the light tight enclosure admits the piston (not shown) which is utilized to raise and lower the wafer platform 23. The back wall 22 of the light tight enclosure has an opening (not shown) therein through which a probe and probe arm can extend to test a wafer on the

At the heart of the wafer handling, positioning, and probing system of this invention is the z, θ stage 100 which has unique structural and functional features now to be described in conjunction with Figs. 12-21. Referring now to Fig. 12, the major components of the z, θ stage 100 are base plate 104, a hollow cylindrical housing 105, a hollow cylindrical rotor 106, and a hollow piston 107. Housing 105 is mounted in an accurately machined recess in the base 104 and is fastened to the base 104 with a plurality of machine screws (not shown) which extend from the bottom of the base 104 into drilled and tapped apertures in the side walls of housing 105. An o-ring 113 provides a seal against leakage of air from the interior 112 to the outside atmosphere at this mounting surface.

A channel 108 is provided in the base 104 to communicate with the central hub 104A into which a hollow stainless steel tube 109 is threaded. Channel 108 and hollow tube 109 communicate vacuum to the hollow interior 110 of the piston 107. This vacuum is communicated through an aperture 146 to an arrangement of grooves on the top surface of the wafer platform 124 as shown in detail in Figs. 20 and 21 to be described below.

A second channel 111 is provided in the base 104 to communicate air under pressure to the open interior 112 underneath piston 107, thereby to drive piston 107 vertically between the stage down and stage up positions. Release of the air pressure in the channel 111 causes the piston 107 to drop of its own weight to the stage down position which is also the wafer test position of the platform 124.

Rotor 106 is mounted within housing 105 for free rotation on a pair of upper and lower bearing assemblies 114 and 115. A shoulder 116 on rotor 106 carries the weight of the rotor on the upper bearing assembly 115. A keeper ring 114A holds the lower bearing assembly 114 and the sealing ring arrangement 117 in position between the inner wall of housing 105 and the outer wall of rotor 106. A gear 118 is mounted with machine screws to a top flange on rotor 106 so that a drive belt 103 may be used to couple the gear 118 to a motor drive arrangement 102 mounted on a bracket 101. The sealing ring arrangement 117 is a special spring expansion sealing ring especially designed for air and vacuum pressure sealing. The sealing arrangement 117 remains stationary against the inner wall of housing 105 and the outer wall of rotor 106 and rotor 106 rotates with respect to the sealing ring 117. This sealing arrangement precludes leakage of air from the interior cavity 112 under piston 107 through the annular space between the outer surface of the rotor 106 and the inner surface of the housing 105.

Piston 107 carries platform 124 on the top end thereof with an o-ring seal 122 preventing leakage of air past the mounting surface between the platform 124 and the piston 107. At the bottom end of piston 107, a pair of special spring expansion sealing rings 119 and 120 are mounted in grooves machined into the piston and held in place by shoulders formed on the bottom of the groove over which the sealing rings are fitted in the assembly process. The outer wall of piston 107 is machined to mate fairly accurately with the inner wall of rotor 106, but sealing ring 119 precludes having to do high accuracy matched machining of these pieces for metal-to-metal seal. Thus, sealing ring 119 precludes the escape of air from the interior 112 past any annular space between the outer wall of piston 107 and the inner wall of rotor 106.

The sealing ring arrangement 120 both seals and provides a sliding bearing surface for the vacuum in cavity 110 and the air pressure in cavity 112. Thus, as the piston 107 is raised by the air pressure in cavity 112, the sealing ring arrangement 120 rides along with the piston on the exterior surface of the hollow tube 109 to provide continuous air/vacuum isolation. Since both the vacuum in cavity 110 to hold a wafer on platform 124 and air pressure in cavity 112 to raise the piston 107 are present at the same time, it is important that the sealing arrangement 120 provide good pressure isolation between the air pressure region 112 and the vacuum pressure 110.

The reciprocating piston 107 is keyed to the rotor 106 utilizing a series of three keys 121A, 121B and 121C, (shown best in Fig. 13) and a plurality of keyways 126A, 126B, and 126C which are machined in the exterior walls of the piston 107. The position of these keys and keyways is purposely non-symmetric about the center axis of the z, θ stage so that the piston 107 can be mounted within the rotor 106 in only one orientation. This is required for the proper positioning of the piston position marker arrangement relative to the optical sensors as will be described below. A keeper ring 122 holds the individual keys 121 in position relative to the rotor 106 utilizing mounting screws 123. As shown in Fig. 13, a plurality of tapped holes 131 cooperates with machine screws (not shown) to mount the platform 124 in a removable fashion to the top of piston 107. An o-ring 123 is mounted in a groove in the exterior surface of piston 107 to provide a soft, silent stop in the stage up position of piston 107. The o-ring 123 contacts the bottom of the keys 121 as the piston rises and the bottom surfaces of the keys bottom out in the keyways.

machined in the platform 124 as shown in Fig. 20 and vacuum picking the wafer off the top surface 23 of the platform and carrying it to a wafer cassette. Following this, the next wafer is vacuum picked out of the cassette and positioned on the wafer platform surface 23. The vacuum on the pick is then removed and the vacuum on the z, θ stage platform 124 is turned on to hold the wafer in position.

The integration of the optical sensors associated with the z, θ stage into an overall safety inhibit circuit arrangement will be discussed in detail below. It should be apparent that the home position sensing for the rotor 106 could be accomplished by other marker and sensor arrangements, including a microswitch arrangement which might utilize a switch actuator carried on gear 118 and a microswitch mounted on a bracket positioned on the exterior of the housing 105. The optical sensor arrangement 142 with marker 141 is preferred because of the position accuracy achievable with that arrangement. The home position sensor is actually integrated into a position control function which determines the actual home position of the rotor 106. This is in contrast to the stage up and stage down optical sensors which only report the position of the stage and do not actually control the stage up and stage down position locations.

Referring now to Figs. 20 and 21, the structural details of the wafer platform 124 will be considered. On the top surface 23 of the wafer platform 124, an arrangement of generally circular grooves 145 is provided. The flat portion of each of the grooves corresponds with the position of a wafer flat. For example, the outline of a wafer is shown in Fig. 20 and the flat of the wafer is aligned with the flat region of the vacuum grooves 145. Central aperture 146 communicates vacuum to the interconnected groove arrangement. A selective groove coupling arrangement is provided by the slotted key 148 which has a plurality of channels 149A and 149B of different lengths therein so that the position of the key 148 controls how many of the circumferential vacuum grooves 145 are connected to vacuum. This provides an easy way of controlling how many grooves receive vacuum for holding wafers of different diameters on the platform 124. In this manner, the entire bottom surface of the wafer can be held tight to the top of the wafer platform 124. Since wafers are sometimes distorted, holding them flat against the platform provides for more accurate probing since the force of the probe tips against the wafer will be more consistent from point to point if the wafer is not deforming as the probe bottoms on the wafer surface.

An arrangement of threaded apertures 147 is provided in the top surface 23 of wafer platform 124 to receive nylon alignment posts at various radial positions. These alignment posts enable a semiconductor wafer to be accurately positioned on the platform 124 with its center concentric with the center of the platform itself.

The r, z stage 150 depicted in Fig. 11 is shown in four different views in Figs. 22 and 25 together with a special view 26 showing the air cylinder drive arrangement for raising and lowering the probe arm to provide the z component of motion of the stage as well as the optical sensor associated with detecting the probe down condition of the stage. It should be understood that the r, z stage 150 could, in some semiconductor wafer test environments, be simply an r stage. It will be apparent from the description below that the z motion component of the r, z stage could readily be eliminated or disabled in situations where the z component is not required or desired for the testing protocol being performed.

The r, z stage 150 includes a base casting 151 which mounts, using bolts through the mounting apertures 152, to the platform 41 as shown in Fig. 11. With appropriate jiggling, the base casting 151 can be positioned on the platform 41 so that the center line of the probe arm 180 intersects the central axis of the z, θ stage 100.

An electric motor 153 is mounted on one end wall of the base casting using mounting screws 154. The shaft 155 of motor 153 is coupled by way of a flexible coupling 156 to a lead screw 157 which extends to the back wall of the casting 151 where it is journaled in a bearing 158. A traveling nut arrangement 159 is carried on lead screw 157 so that the electric motor and lead screw arrangement can drive the coupling arm 160 and carriage platform 161 back and forth in the r direction, i.e., along the radius of the wafer platform 124 at the z, θ stage. The carriage platform 161 is mounted on a ball slide arrangement 162. The stationary portion 163 of the ball slide 162 is mounted to the base casting 151 and the sliding portion 164 is mounted to the carriage platform 161 to translate therewith.

An optical sensor circuit board 165 is mounted in a stationary position on a bracket arrangement 166 which is in turn mounted on the base casting 151. A pair of optical sensors 167 and 168 are mounted to the circuit board 165 and electrical connectors 165A and 165B are provided for power input and signal output. An L-shaped bracket 169 is mounted to the carriage platform 161 and carries thereon a position flag 170 which functions together with the optical sensors 167 and 168 (as best seen in Fig. 23) to signal the position of the carriage

to determine the position of the center of the wafer on the wafer platform 124 and also the wafer size, utilizing a procedure described in detail below in conjunction with the explanatory diagram of Fig. 32 and the software flow chart of Fig. 41.

Figs. 27, 28 and 28A depict an optional protective traveling shroud 211 mounted in the light tight enclosure formed underneath the top cover 13 of the tester cabinet. The traveling shroud 211 basically comprises a box-shaped sheet metal enclosure having a top surface 215 in which a circular opening slightly smaller than the outer diameter of the wafer platform 23 is formed. The traveling shroud 211 is arranged to rest on the bottom floor 20 of the light tight enclosure when the wafer platform 23 is in the stage down position. As shown in Fig. 28A, an arrangement of four corner guide pins 214 and channels 213 provide positive guidance for the traveling shroud 211 in its upward travel.

As the wafer platform 23 moves up, the outer circumferential edge contacts the marginal edge of the circular hole in the top 215 of the traveling shroud so that the shroud 211 will move upward with the wafer platform 23. The lip 212 on the bottom of the shroud has overall dimensions greater than the door opening in the top 13 of the cabinet so that shroud 211 cannot be removed from the cabinet without raising the top 213. A rectangular cut-out 217 in the back wall of the shroud cooperates with the opening in the back wall 22 of the light tight enclosure to admit the probe head into the enclosure when the wafer platform 23 is in the stage down position. A U-shaped plastic piece 216 is glued to the edge of the shroud aperture to eliminate any sharp metal cutting edge at that point and to deaden the sound of the top of the wafer platform 23 striking the edge of the top 215 of the shroud.

The automated resistivity tester which forms the preferred embodiment of this invention incorporates not only the z, θ stage 100 and the r, z stage 150, but also a sophisticated real time control and data acquisition subsystem based on microcomputer technology. A block diagram of this overall computer-based control and data acquisition system is depicted in Fig. 29. Components within rectangle 220 comprises a standard microcomputer system in which a central processing unit (CPU) 221 communicates by address, data and control buses 222, 223 and 224, respectively, with program and data storage memory 225, serial I/O ports 226 and 227 and programmable I/O ports

228, 229, 230 and 231. This is a standard microcomputer architecture and the details of the operation of this portion of the system are very well known and need not be described in detail here.

The serial I/O ports 226 and 227 communicate with a main or host computer 240. In one embodiment of the automated resistivity tester system, the main computer 240 is the master computer and the operation of the microcomputer system 220 is slaved to that computer. In other words, the commands for the automated resistivity tester in a control and data collection mode are downloaded from the main computer 240. A more limited, automated resistivity tester can be implemented on a stand alone basis utilizing microcomputer 220 programmed by way of an operating program in memory section 225 to perform limited resistivity tester functions. In that embodiment, a printer interface for directly printing out the data collected would be provided, but the system would not include features of data base collection, storage and management. In a more sophisticated system, the main computer 240 is hooked up to a graphics printer and to a CRT terminal for displaying the results of the resistivity testing on a particular wafer in the form of a contour map and/or diameter scan. The main computer 240 will also include a mass data storage device.

P.I.O. port 228 serves the keyboard input and LCD display output functions. Keyboards 15 and 17 communicate via bus 251 to input manual control signals into computer system 220. Computer system 220 communicates data, status and other information to LCD display 16 via output signal bus 252.

P.I.O. ports 229 and 230 provide output control and input data gathering functions for the operation of the z, θ stage and the r, z stage as well as the door 19 and the reflection sensor 210. P.I.O. port 230 is dedicated to the motor control and position reading functions of motor control circuit 283 associated with the probe arm motor and motor control circuit 284 associated with the rotary stage motor. The probe arm motor controls the r position of the probe in the r, z stage and the rotary stage motor 102 controls the θ position of the wafer platform in the z, θ stage. Data is provided on the target motor position to each of the motor control circuits 283 and 284 via data bus 278. Separate status signal lines 279 and 281 feed back motor control status information to P.I.O. port 230 and separate control buses 280 and 282 feed separate control signal information to motor control circuits 283 and 284. Status signal bus 279 includes a NOT BUSY status lead 279 which is coupled into safety inhibit system 261. Similarly, status bus 281 from motor

UP AIR line, the cylinder 184 moves the probe up. Similarly, when air is supplied to the DOWN AIR line by operation of solenoid 313, the piston 187 is forced downward.

The overall schematic circuitry of Fig. 30 will be utilized in conjunction with the inhibit system circuitry shown in Fig. 31 and the software flow charts shown in Figs. 34-41 to illustrate the overall function of the system in a standard sequence of steps utilized to make a measurement on the wafer.

The safety inhibit system circuitry 261 shown in Fig. 31 incorporates a programmed array logic - (PAL) chip 320 which receives a plurality of sensor signal inputs and status signal inputs from the motor control circuits 283 and 284 and provides a plurality of enable and/or disable (inhibit) output signals which are logical combinations of the sensor and status signal inputs. Four of the control signals from P.I.O. 229, namely, stage up, stage down, probe down and door direction signals, are individually fed to a series of AND gates 321 followed by inverter amplifiers 322 to provide stage up, stage down, probe down and door direction command signals provided that the outputs of the AND gates 321 are enabled by coincident enabling signals on the other inputs. In addition, the PAL chip 320 provides inhibit outputs for the rotary stage motor and the probe arm motor under certain logical combinations of the sensor and status signals input to the PAL chip. Since the door motor requires both a door direction and a door enable command before the door motor operates, only one of these control signals is coupled through an AND gate. The probe up command is always a safe command in that there is never any danger in raising the probe since that action will never interfere with any other functional activity or cause a dangerous or damaging positional conflict between various components of the system.

It can thus be seen that the PAL chip is an arbitrator of the propriety of processing a particular control signal depending on the position or movement status of the components of the system. For example, if the computer system 220 issues a STAGE UP command, and the probe 200 is not in a probe parked position, the STAGE UP command should be disabled unless and until the probe is moved to the probe parked position. Similarly, a stage up command conflicts with a door closed condition. Accordingly, the PAL chip is programmed to disable the input to the AND gate servicing the STAGE UP control signal if the probe parked sensor is not ON or the door open sensor is not ON. Both of those sensors must have a true or ON output before the STAGE UP command can be

processed. Essentially, the same condition is true of a stage down control signal. It should not be processed unless the probe is in the parked position and the door is open.

Consider now the PROBE DOWN command. This command should not be processed if either the wafer platform is not down or the stage motor is busy or the probe motor is busy. Most importantly, the probe should not be dropped onto a wafer on the platform if either of the motors is busy moving the wafer platform to a new location. The door direction control signal should not be passed to the door direction motor if, for example, the stage down status signal is not present.

The PAL chip will produce inhibit signals for both the rotary stage motor and the probe arm motor anytime the probe down sensor is ON since the platform should not move when the probe is down on the wafer.

Additional, more complicated safety inhibit system functions could also be implemented in a system which utilizes the reflection detector 271 to map the position of the wafer on the wafer platform. For example, if a system has detected the center of the semiconductor wafer relative to the center of the platform and has calculated the radius of the wafer and determined the position of the wafer flat, the permitted r, θ coordinates at which the probe head should be dropped could be mapped in memory and a separate arrangement could be provided for processing of the PROBE DOWN signal which would not place the probe in contact with the area of the wafer.

From the above discussion, the logical equations which are necessarily embodied in the PAL chip are readily ascertainable and the person of skill in the art can program the appropriate logic equations to achieve the enable/disable and inhibit logic required by the system.

Fig. 33 shows the overall software control architecture of the automated resistivity test system depicted in schematic block diagram form in Fig. 29. Two-way communications from the host computer 240 are handled by way of interrupt input handlers and interrupt output handlers. The host computer issues a command to the microcomputer system 220 which is fed to a command line interpreter which either validates or invalidates the command. If the command is a valid one, it is acknowledged to the host and interpreted by the computer system 220 to issue appropriate signals to P.I.O. ports, etc., to provide control and/or data signals to one or more of the modules of the system which essentially function in parallel. These modules are the motor controls, the pneumatic (vacuum/air) controls, analog measurement circuitry, the current sen-

form a measurement is interrupted and the measurement can not be performed unless and until some remedial action is taken to fix whatever problem is precluding satisfactory execution of the program.

The next routine to be executed is the close door routine. The first step of that routine is to test whether the stage down sensor is ON. If that test returns a no condition, the status is updated and return not acknowledged is performed. Next, the time out counter is set and the system alternately checks for the ON condition of the door sensor or time out of the timer. Whichever of these test returns a YES first will result in an updating of status and turning off the door motor. If the door closed sensor ON test first returns the YES condition, a return acknowledge will be sent. If the system first times out, a return not acknowledge will be sent.

The next step in the sequence is shown in Fig. 38 and involves moving to an initial $r, 0$ position. The first step in this routine is to check whether the probe is up and the stage is down. The next test is whether the r, θ coordinates to which the probe head is commanded are out of limits for the particular wafer size. If that test is NO, the system sends move commands to the motor controllers providing the final position coordinates to which the z, θ stage and the r, z stage should be sent, i.e., the final r and θ coordinates. The next step is to set a time out counter and then enter a loop of tests checking for the completion of moving of the rotary stage motor and probe arm motor, checking to see whether the r stage reaches the home position while the motor is still moving, and testing whether the time out of the timer has occurred. In normal execution, the motor done moving test will be satisfied first and the status updated and a return acknowledge will be provided. If either of the other tests results in YES condition first, the move will be aborted, a status flag updated and a return not acknowledge provided.

Figs. 39 and 40 illustrate the routines for lowering the probe and raising the probe. Each of these routines is straightforward and need not be described here.

Fig. 41 illustrates the routine for determine the wafer size and center coordinates of the wafer relative to the wafer platform on which it rests. The first thing that this routine does is to check whether the stage is down. Assuming it is, the edge counters for the wafer edge locations are initialized, followed by a step of initializing the r, z stage time out counter. The system then issues a command to the r, z stage to move the probe arm to the home position, i.e., the center of the wafer platform. The

probe will thus begin moving along the first probe path shown in Fig. 32, accompanied by the reflective sensor moving on a first sensor path shown in Fig. 32. The system then activates the sensor light source and goes into a loop to sample the output of the fiber optic detector to determine whether the reflection sensor is ON or the r, z stage time out has occurred. This loop continues to run until the reflection sensor turns ON, at which point the system reads and stores the motor position of the probe arm motor and the rotary stage motor as the r, θ coordinates of the first edge. Since the displacement of the reflection sensor relative to the probe head is known, the actual coordinates to be recorded are the displaced $r1, \theta1$ coordinates of the sensor itself. These can readily be calculated from the motor position information received back from the motor controller for the r, z stage and the z, θ stage.

The system then looks to determine whether the r, z stage has reached the home position or a time out has occurred on the r, z stage. Any r stage time out will cause a status update and a return not acknowledged condition. Assuming the r, z stage reaches the home position, the next step is to initialize the time out counter again and to issue a command to rotate the z, θ stage by 120° . The program then enters a loop to determine whether the z, θ stage has finished moving by looking at the status of the rotary stage motor NOT BUSY signal fed back from the motor controller circuit 284 shown in Fig. 29. Once it has been detected that the z, θ stage has stopped moving, the time out counter is again initiated and a command to the motor control circuit 283 to drive the probe arm toward the probe park position. The system then enters the same loop of sampling the fiber optic detector to determine whether it is ON and whether a time out of the r, z stage has occurred. Once the sensor ON test returns as NO, the motor position - (or alternatively the sensor position) is calculated therefrom is stored as the coordinates of edge point 2, i.e., $r2, \theta2$. The system then enters a loop to determine whether the r, z stage is at the probe parked position, looking at the probe parked sensor, or whether the r, z stage time out has occurred. Assuming that the r, z stage reaches the probe parked position, the system then again initiates a time out counter and issues another stage rotate 120° command. The software executes exactly the same routine to determine the coordinates of the edge 3 point as the $r3, \theta3$ coordinates shown in Fig. 32. The coordinates of the center of the wafer ($rc, \theta c$) can be determined by simple trigonometric function calculations. The three edge coordinates determine two chords of a circle. The

means between a parked position in which a test probe thereon is positioned adjacent and clear of said platform and accurately located test positions along a radius of said platform.

2. The system of claim 1, wherein said carriage means is adapted to carry a test probe which includes at least one test probe element for contacting or approaching the surface of a semiconductor wafer; and said carriage means includes a probe arm for carrying a test probe; arm mounting means for mounting said probe arm in a cantilevered manner at one end for translation orthogonal to said platform between probe up and probe down positions; and probe drive means coupled to said probe arm to drive said probe arm between said probe down and probe up positions.

3. The system of claim 1, further comprising probe location sensor means associated with said carriage means for sensing when said test probe means is in said parked position; platform position sensor means associated with said wafer handling stage means for sensing when said platform is in said wafer test position; control means coupled to said platform and stage drive means for controlling the operation thereof; and inhibit means coupled between said control means and said platform and stage drive means and being coupled to said probe position and platform position sensor means for sensing the state thereof and for inhibiting operation of said platform drive means by said control means except when said probe position sensor means senses that said carriage means is in said parked position and for inhibiting operation of said stage drive means by said control means except when said platform position sensor means senses that said platform is in said wafer test position.

4. The system of claim 2, further comprising probe position sensor means associated with said carriage means for sensing when said test probe means is in said parked position; platform position sensor means associated with said stage means for sensing when said platform is in said wafer test position; and probe status sensor means for sensing when said probe arm is in said probe up position; control means coupled to all said drive means for controlling the operation thereof; and inhibit means coupled between said control means and all of said drive means and being coupled to all said sensor means for sensing the state thereof and for inhibiting operation of said platform drive means by said control means except when said probe position sensor means senses that said carriage means is in said parked position, for inhibiting

operation of said stage drive means by said control means except when said platform position sensor means senses that said platform is in said wafer test position, and for inhibiting operation of both said stage and carriage drive means except when said probe status sensor senses that said probe arm is in said probe up position.

5. The system of claim 3 or claim 4, wherein said stage drive means and said carriage drive means each include a drive control circuit providing an output signal on a drive busy lead that indicates when said associated drive means is busy, said inhibit means is coupled to said drive busy leads and further performs the function of inhibiting operation of said probe drive means to lower said test probe means when either of said drive busy leads indicates that said associated drive means is busy.

6. The system of any of claims 1 to 5, further comprising a light tight housing surrounding at least said platform of said stage means including an access door therein facing said wafer stage and positioned intermediate said wafer load position and said wafer test position of said platform; means mounting said access door for translation between a closed position and an open position which permits said platform to translate between said wafer load and wafer test positions; and door drive means for driving said door between said open and closed positions.

7. The system of claim 6, further comprising probe position sensor means associated with said carriage means for sensing when said test probe means is in said parked position; platform position sensor means associated with said stage means for sensing when said platform is in said wafer test position; door sensor means for sensing when said access door is in said open position; control means coupled to said platform and stage drive means and said door drive means for controlling the operation thereof; and inhibit means coupled between said control means and said platform and stage drive means and said door drive means and being coupled to said probe position and platform position sensor means and said door sensor means for sensing the state thereof and for inhibiting operation of said platform drive means by said control means except when said probe position sensor means senses that said carriage means is in said parked position and said door sensor means senses that said door is in said open position and for inhibiting operation of said carriage drive means and said door drive means by said control means except when said platform position sensor means

to determine from said coordinates of said edge points the r, θ coordinate of the center of said wafer and the size of said wafer.

16. A stage for carrying a workpiece and having the capability of translating said workpiece vertically between a stage down and a stage up position and of rotating said workpiece about a central axis of said stage, said stage comprising a hollow cylindrical housing, a hollow cylindrical rotor mounted within said housing and being carried on a pair of upper and lower bearing assemblies to provide free rotary motion of said rotor within said housing, a cylindrical piston mounted within said rotor and having one end thereof extending above said rotor and carrying a platform for said workpiece thereon, said piston being keyed to said rotor with a cooperating key and keyway arrangement for rotation of said piston with said rotor; a platform drive means communicating with said piston to drive said piston out of and into said rotor to translate said platform between said stage up and said stage down positions; a stage drive means communicating with said rotor to produce rotation thereof within said housing.

17. The system of claim 16, wherein said piston is a hollow piston with the interior thereof communicating with a source of vacuum; said platform includes an arrangement of interconnected grooves formed in a top face thereof and an central aperture extending through said platform to communicate with the interior of said piston to couple vacuum to said grooves to hold said workpiece on said platform.

18. The system of claim 16, further comprising a base plate; said hollow housing being mounted on said base plate and having a fluid sealing means therebetween to prevent escape of fluid from the interior of said housing at the mounting interface; fluid sealing means extending between an outer wall of said rotor and an inner wall of said housing to prevent escape of fluid from the interior of said housing between said respective walls; said piston being mounted for translation within said rotor with a fluid tight sealing arrangement between the outer wall of said piston and the inner wall of said rotor; and means communicating fluid under pressure through said base plate to the interior of said housing to drive said piston.

19. The system of claim 18, wherein said piston is a hollow piston; a hollow tube is mounted to said base plate at one end at a position concentric with said piston and extending into the hollow interior

thereof; a fluid sealing means is interposed between and interior wall of said piston and the exterior of said hollow tube to provide fluid pressure isolation between the interior of said piston and the interior of said housing; a channel being provided in said base and communicating with said hollow tubing to supply vacuum to said interior of said piston; said platform includes an arrangement of interconnected grooves formed in a top face thereof and a central aperture extending through said platform to communicate with the interior of said piston to couple said vacuum therein to said grooves to hold said workpiece on said platform.

20. The system of any of claims 16 to 19, further comprising a position marker carried on an exterior wall of said rotor to indicate the home position of said rotor; and an optical sensor mounted in said housing at the level of said position marker for sensing when said position marker is directly opposite said sensor to signal that said rotor is in said home position.

21. The system of claim 20, further comprising a position marker carried on an exterior surface of said piston for indicating when said piston is in a test position such that said platform is in said wafer test position; said rotor having a window through the wall thereof which is positioned opposite said position marker on said piston when said rotor is in said home position; and optical sensor means mounted in said housing opposite said window in said wall of said rotor for sensing when said piston is in said test position.

22. In a method for detecting the position coordinates of the center of a substantially circular semiconductor wafer resting on a platform capable of rotating about a central axis defining the origin of an r, θ coordinate system and for determining the diameter of said wafer, the steps of:

disposing a sensor above said platform; moving said sensor along a first path which intersects said wafer at a first circular edge portion thereof;

registering the $r1, \theta1$ position coordinates of said sensor when it detects a first edge point of said wafer;

moving said sensor along a second path which intersects said wafer at a second circular edge portion thereof;

registering the $r2, \theta2$ position coordinates of said sensor when it detects a second edge point of said

means to lower said test probe means when either of said drive busy leads indicates that said associated drive means is busy.

26. The system of any of claims 23 to 25, wherein said mounting means comprises a hollow cylindrical housing, a hollow cylindrical rotor mounted within said housing and being carried on a pair of upper and lower bearing assemblies to provide free rotary motion of said rotor within said housing, a cylindrical piston mounted within said rotor and carrying said platform on one end thereof which extends outside said rotor, said piston being keyed to said rotor with a cooperating key and keyway arrangement for rotation of said piston with said rotor; said platform drive means comprising means communicating with said piston to drive said piston out of and into said rotor; said stage drive means comprising means communicating with said rotor to produce rotation thereof within said housing.

27. The system of claim 26, wherein said piston is a hollow piston with the interior thereof communicating with a source of vacuum; said platform includes an arrangement of interconnected grooves formed in a top face thereof and an central aperture extending through said platform to communicate with the interior of said piston to couple vacuum to said grooves.

28. The system of claim 26, further comprising a base plate; said hollow housing being mounted on said base plate and having a fluid sealing means therebetween to prevent escape of fluid from the interior of said housing at the mounting interface; fluid sealing means extending between an outer wall of said rotor and an inner wall of said housing to prevent escape of fluid from the interior of said housing between said respective walls; said piston being mounted for translation within said rotor with a fluid tight sealing arrangement between the outer wall of said piston and the inner wall of said rotor; and means communicating fluid under pressure through said base plate to the interior of said housing to drive said piston.

29. The system of claim 28, wherein said piston is a hollow piston; a hollow tube is mounted to said base plate at one end at a position concentric with said piston and extending into the hollow interior thereof; a fluid sealing means is interposed between and interior wall of said piston and the exterior of said hollow tube to provide fluid pressure isolation between the interior of said piston and the interior of said housing; a channel being provided in said base and communicating with said

hollow tubing to supply vacuum to said interior of said piston; said platform includes an arrangement of interconnected grooves formed in a top face thereof and an central aperture extending through said platform to communicate with the interior of said piston to couple said vacuum therein to said grooves.

30. The system of any of claims 26 to 29, further comprising a position marker carried on an exterior wall of said rotor to indicate the home position of said rotor; and an optical sensor mounted in said housing at the level of said position marker for sensing when said position marker is directly opposite said sensor to signal that said rotor is in said home position.

31. The system of claim 30, further comprising a position marker carried on an exterior surface of said piston for indicating when said piston is in a test position such that said platform is in said wafer test position; said rotor having a window through the wall thereof which is positioned opposite said position marker on said piston when said rotor is in said home position; and optical sensor means mounted in said housing opposite said window in said wall of said rotor for sensing when said piston is in said test position.

32. The system of any of claims 23 to 31, further comprising a protective shroud mounted within said light tight housing over said platform, said shroud having a top surface defining an opening having generally the same geometric shape as said platform and being dimensioned to have a marginal edge portion contacted by a marginal edge portion of said platform as it travels from the wafer test position toward the wafer load position so that said shroud will thereafter travel with said platform, said shroud having sidewalls extending from said top surface toward said access door to block access to regions under said platform over a major portion of the peripheral area of said platform.

33. In a computer controlled machine having a number of mechanical components which move relative to each other under computer control of associated drive means, a plurality of said components having possible positions which conflict with safe movement of other components, sensor means for reporting the positions of said plurality of components, computer means for communicating control command signals to said drive means, and logic means coupled to said sensor means and said computer means for disabling one of said control command signals to one of said drive

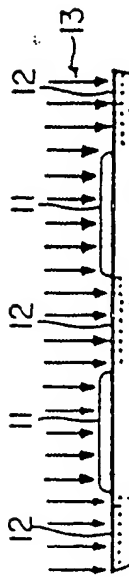


FIG. 1A
(PRIOR ART)

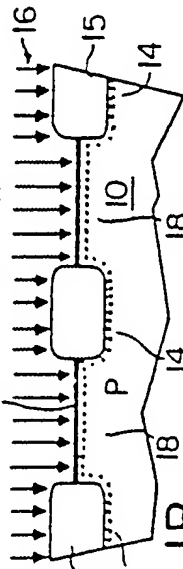


FIG. 1B
(PRIOR ART)

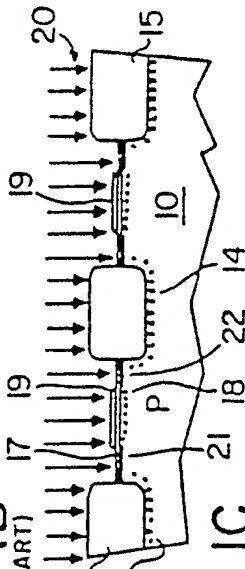


FIG. 1C
(PRIOR ART)

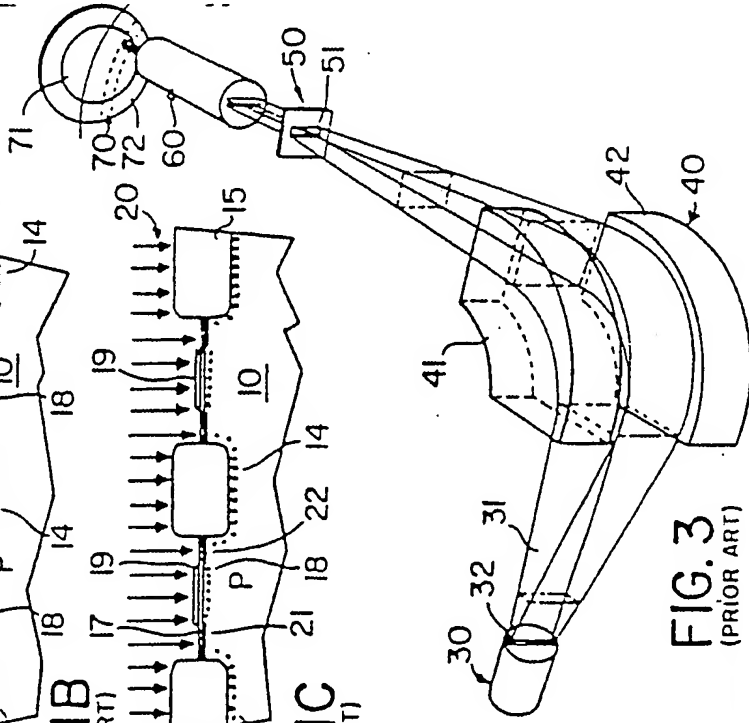


FIG. 3
(PRIOR ART)

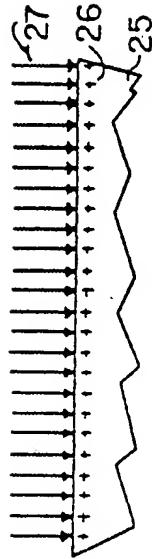


FIG. 2
(PRIOR ART)

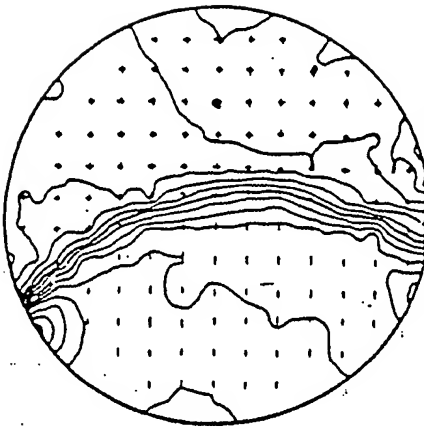


FIG. 4

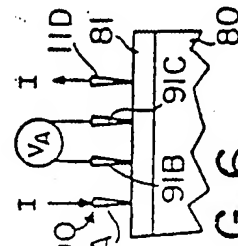


FIG. 6
(PRIOR ART)

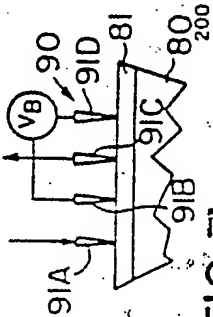


FIG. 7
(PRIOR ART)

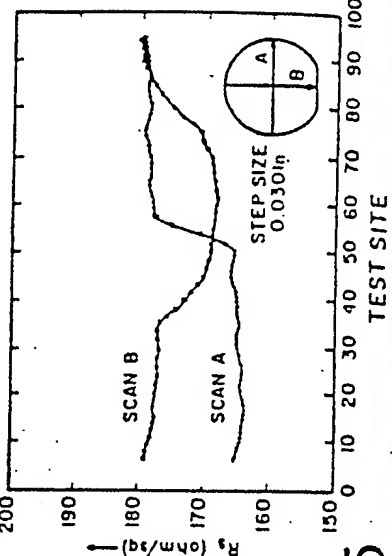


FIG. 5

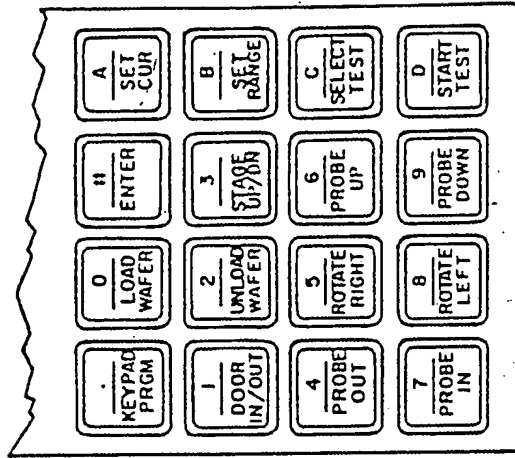


FIG. 9

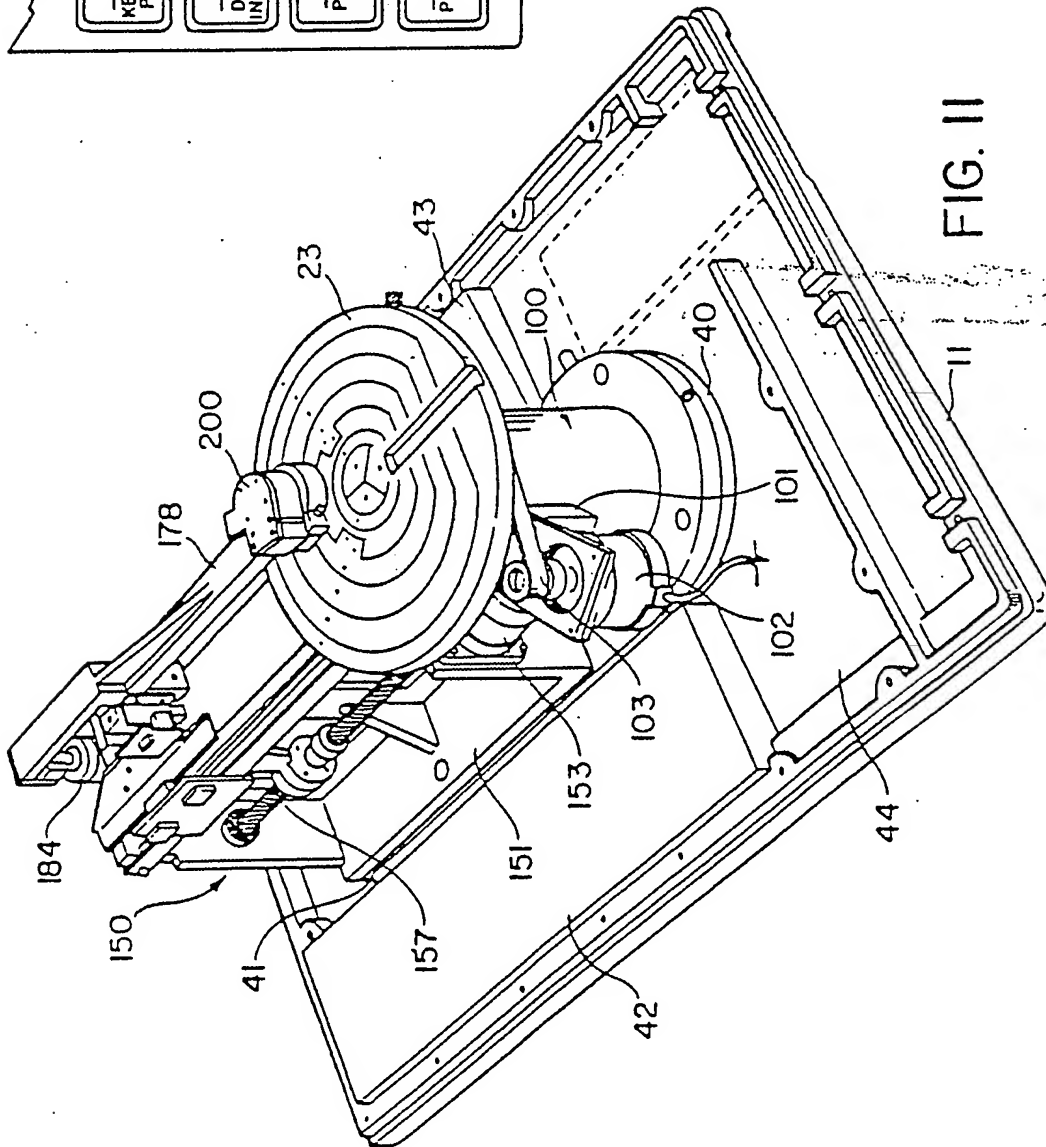


FIG. 11

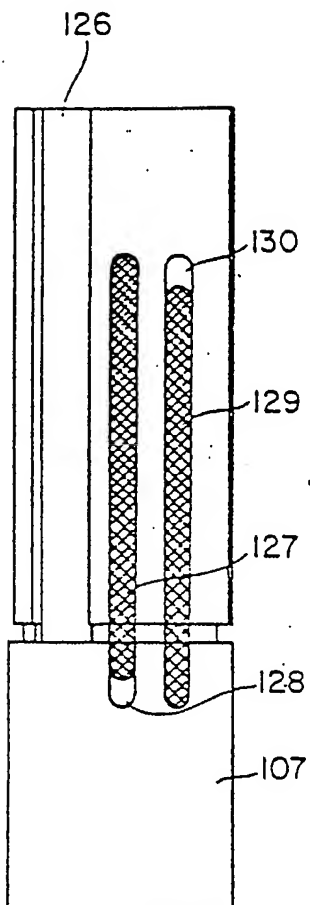


FIG. 15

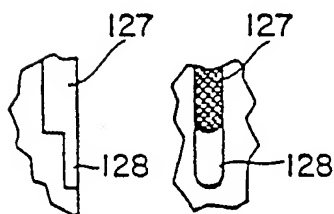


FIG. 16

FIG. 17

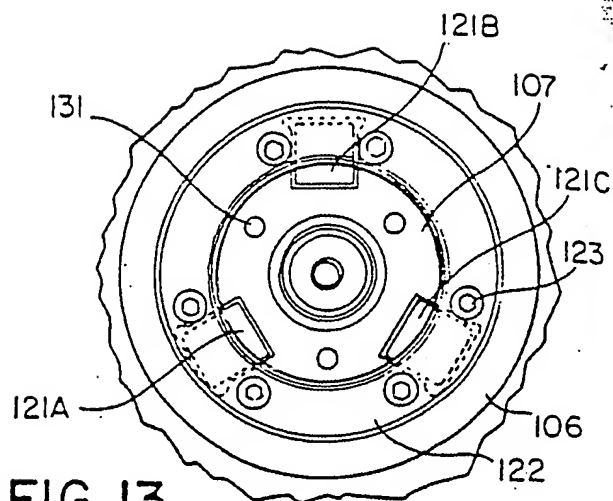


FIG. 13

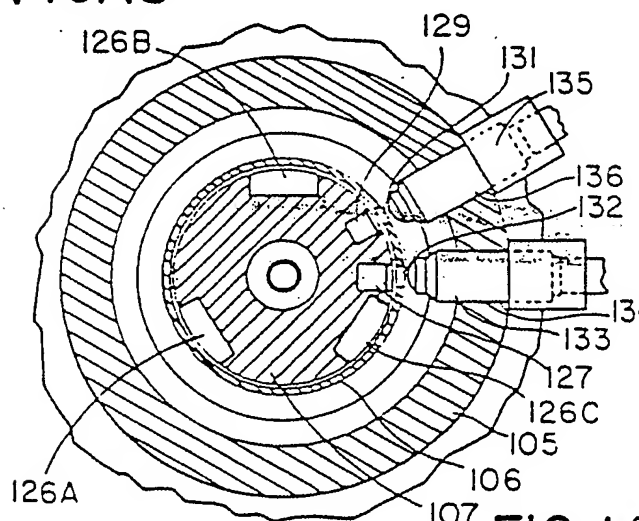


FIG. 14

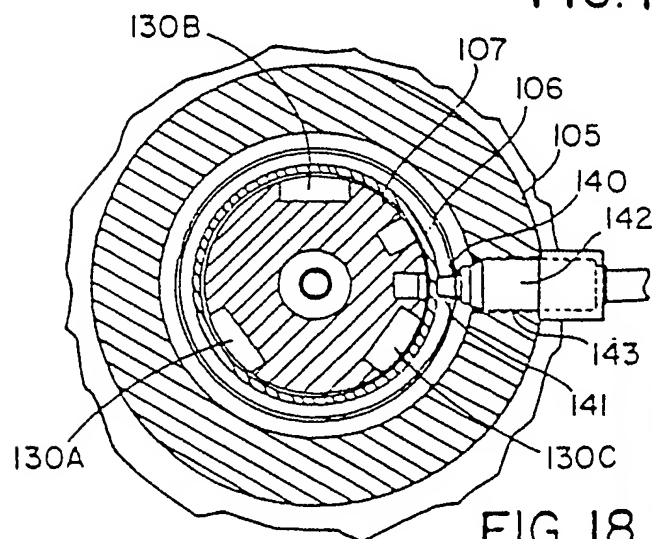


FIG. 18

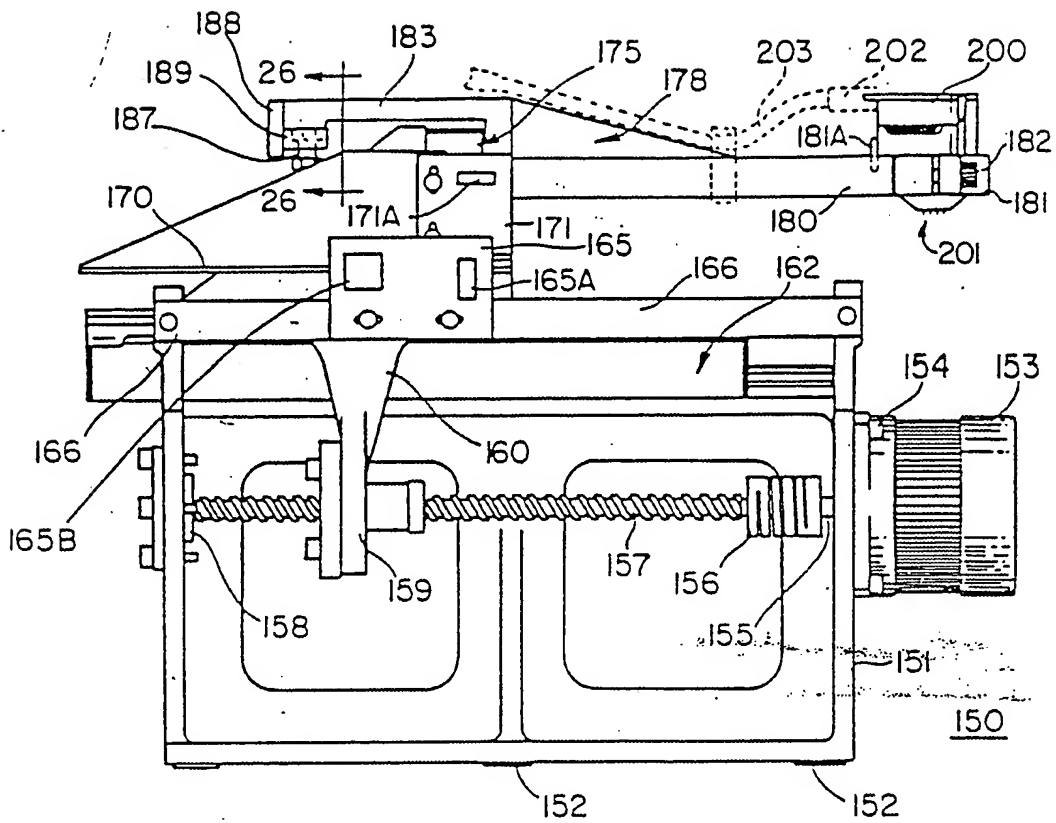


FIG. 22

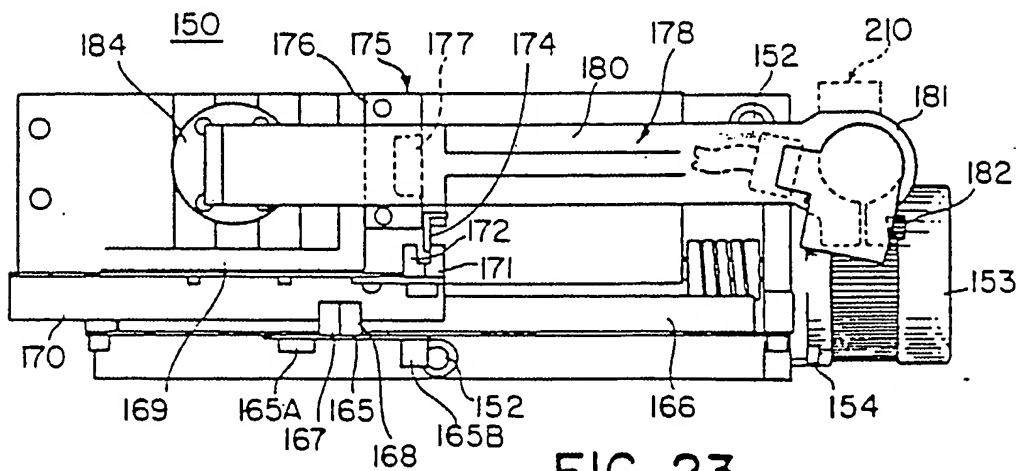


FIG. 23

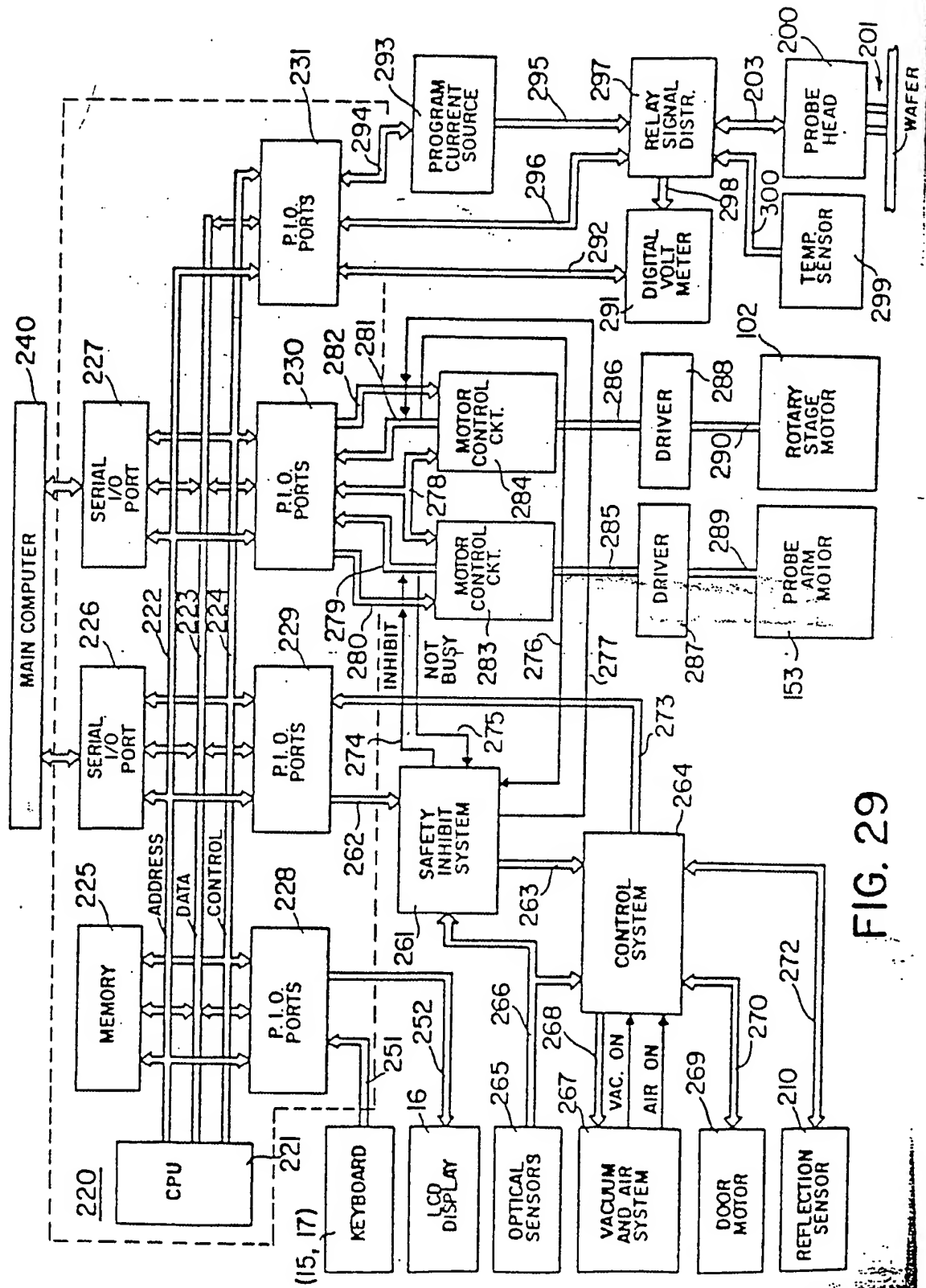


FIG. 29

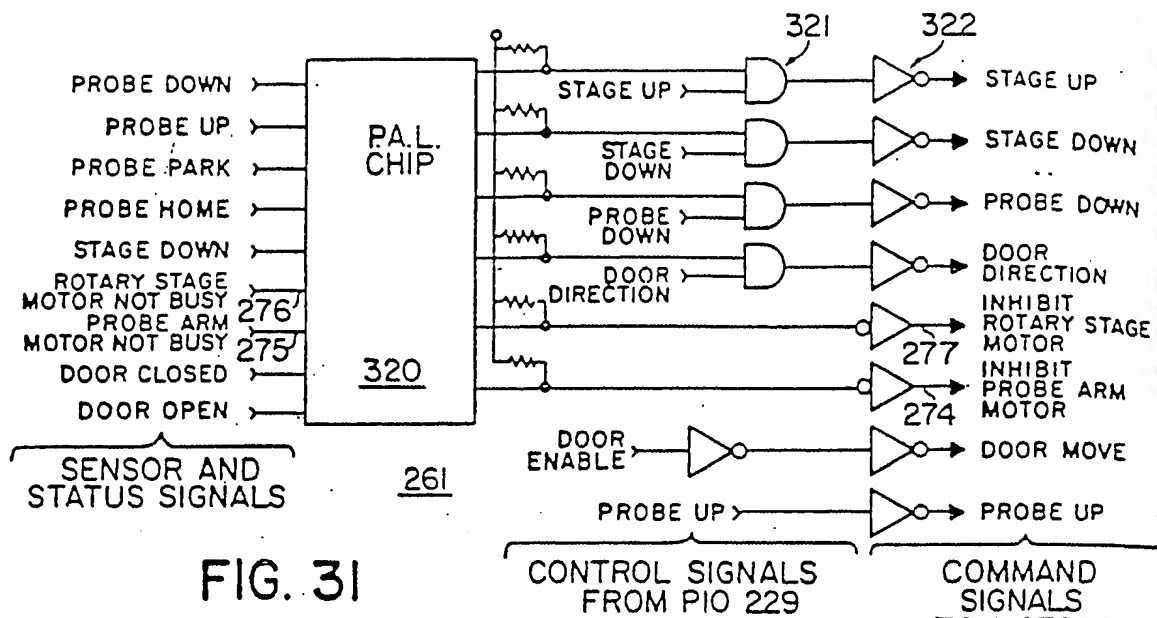


FIG. 31

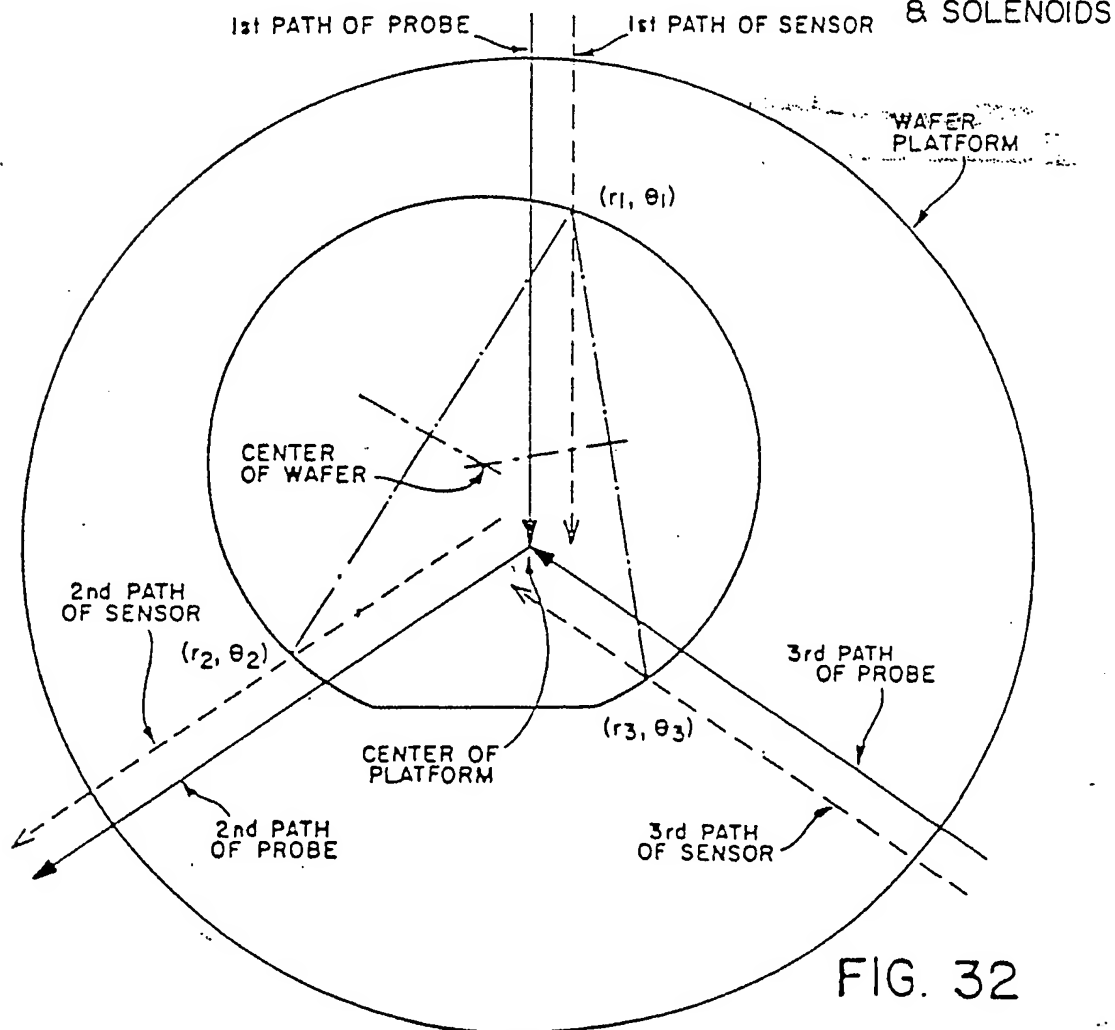
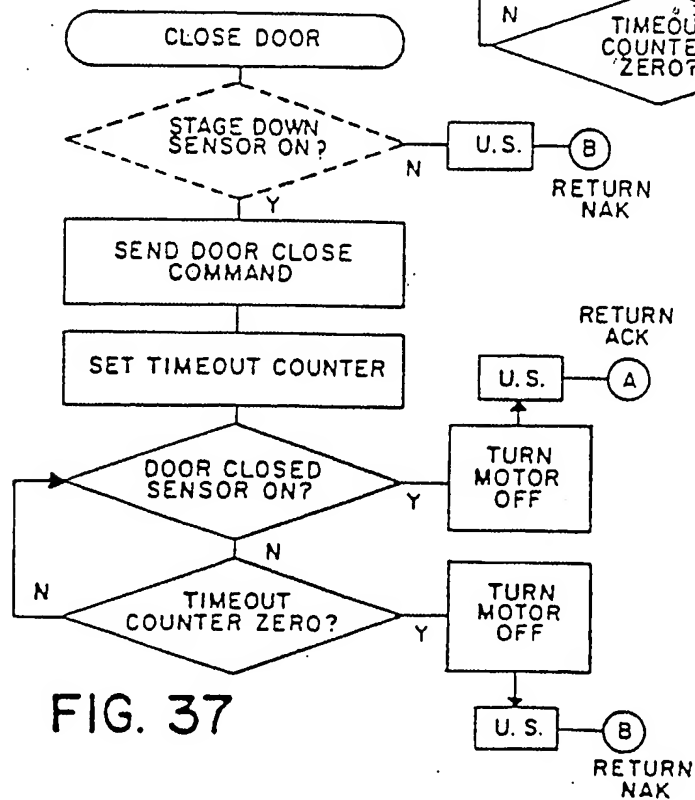
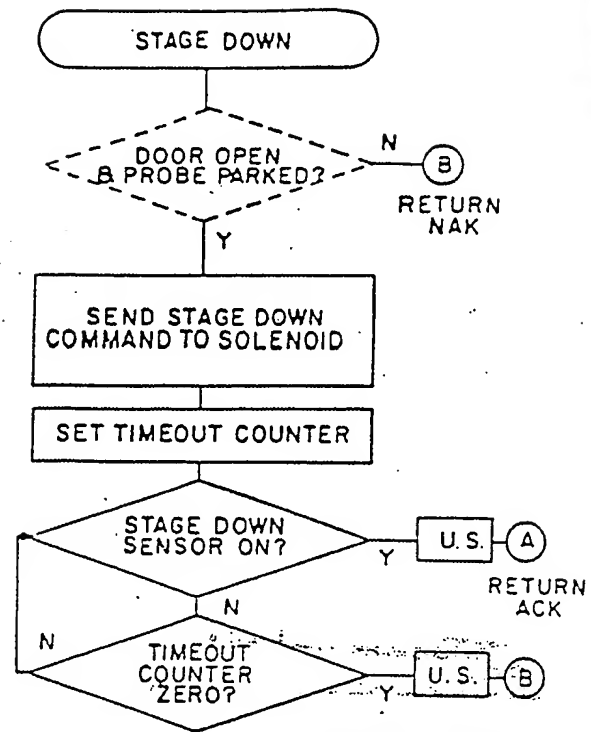
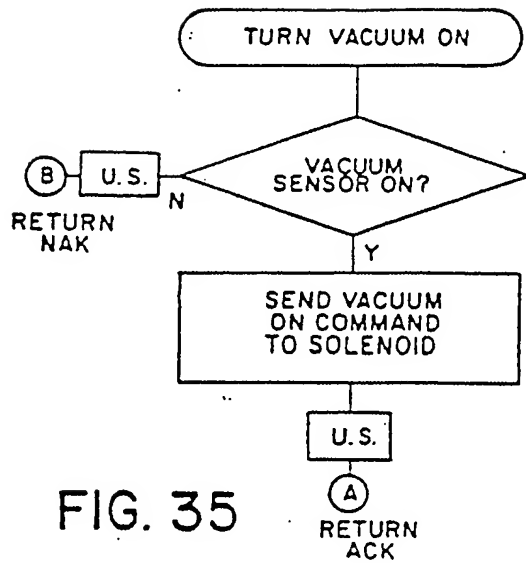


FIG. 32



**This Page is Inserted by IFW Indexing and Scanning
Operations and is not part of the Official Record**

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ **BLACK BORDERS**
- ☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**
- ☐ **FADED TEXT OR DRAWING**
- ☐ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**
- ☐ **SKEWED/SLANTED IMAGES**
- ☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**
- ☐ **GRAY SCALE DOCUMENTS**
- ☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**
- ☒ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**
- ☐ **OTHER: _____**

IMAGES ARE BEST AVAILABLE COPY.

As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.